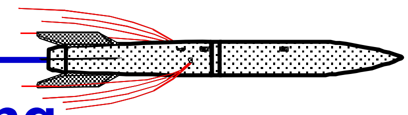
Test Before Flight:



Wind Tunnel Technology for Aerodynamic Testing

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under contract DE-AC04-94AL85000.

Aerosciences at Sandia

Sandia’s missions support national security

- Primary mission is stewardship of the nuclear stockpile
- Other missions are derived from our nuclear mission, including non-proliferation, surveillance, etc.
- We collaborate with DoD, NASA, and industry on other programs in the national interest



Many of these missions are centered upon flight hardware

- Flight vehicles for nuclear weapons
- Precision weapons
- Missile defense
- Future prompt response systems
  - Rockets
  - Re-entry vehicles


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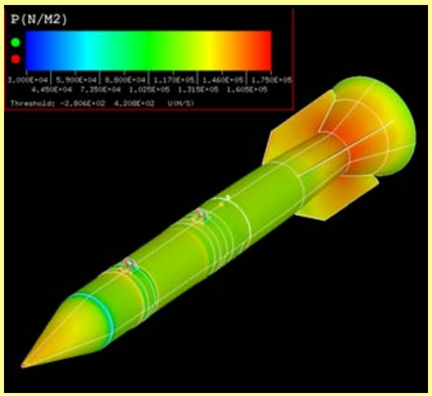
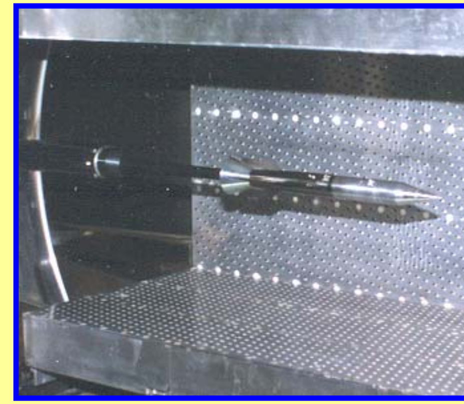
The Role of the Wind Tunnels

Flight Test



Modeling & Simulation



Ground Test

We support Sandia's aero needs by:

- Aerodynamic characterization of vehicles
- Testing of flight components
- Investigating fundamental aerospace physics
- Providing data to develop and validate computational models

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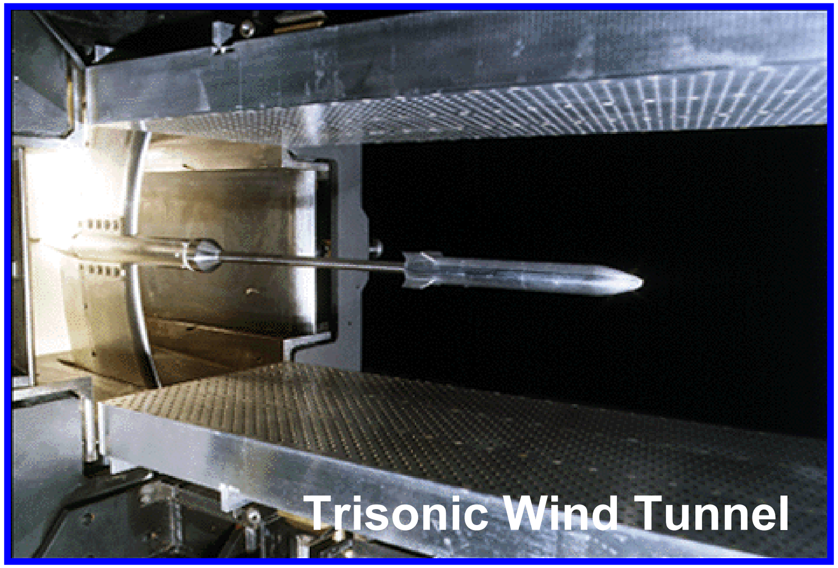
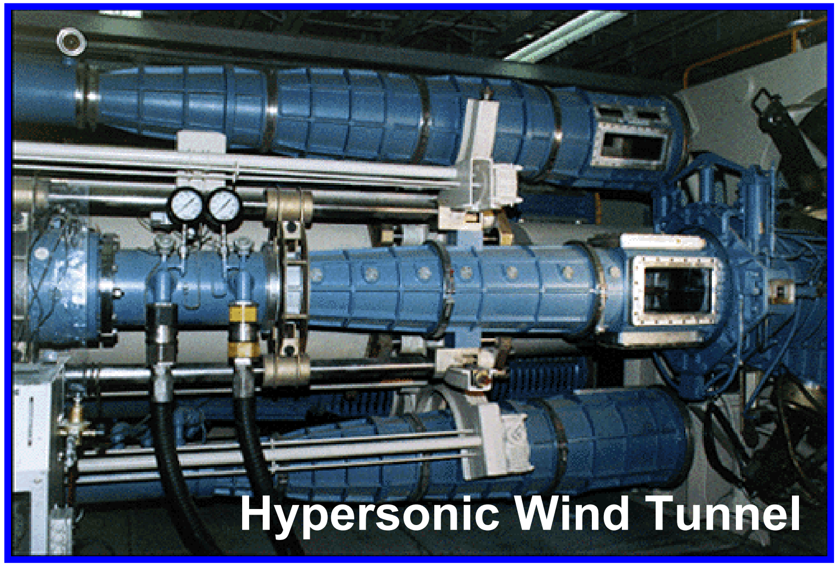
Experimental Aerosciences Facility





Trisonic Wind Tunnel (TWT)

- Mach 0.5 – 3
- Gravity bombs, missiles, commercial aerospace

Hypersonic Wind Tunnel (HWT)

- Mach 5, 8, 14
- Re-entry vehicles, rockets

High-Altitude Chamber (HAC)

- Satellite components

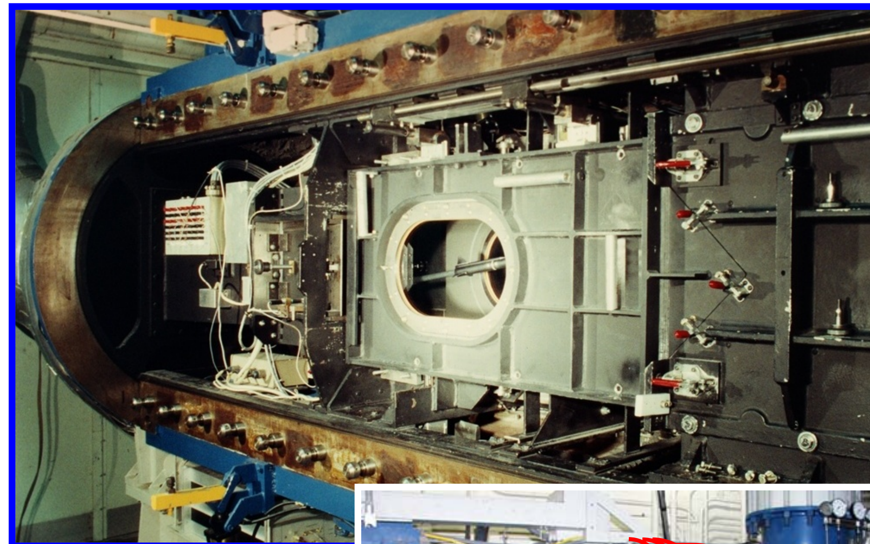
Trisonic Wind Tunnel (TWT)

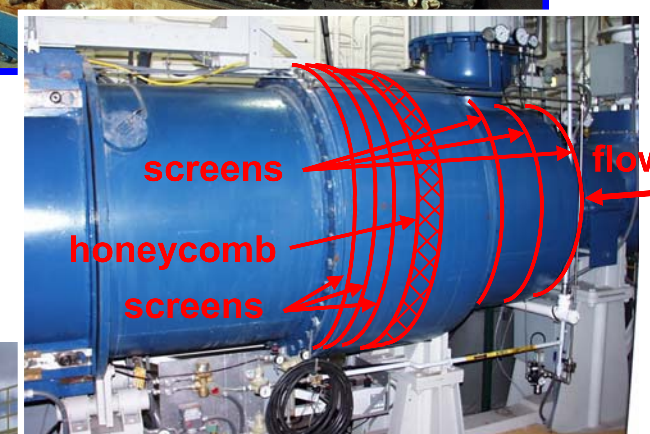
Blowdown Wind Tunnel

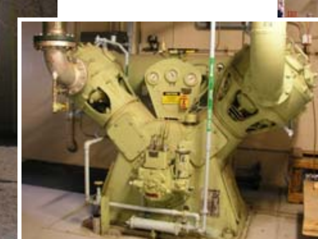
- Runs for 30-50 seconds at a time
- Turnaround of about 20-30 minutes
- Supplied by high-pressure air
- Exhausts to atmosphere
- 12" square test section

Flow Control

- A series of valves control the pressure and the flow rate
- Downstream of the valves are screens and honeycomb to “smooth” the flow
- The test section is where we do business







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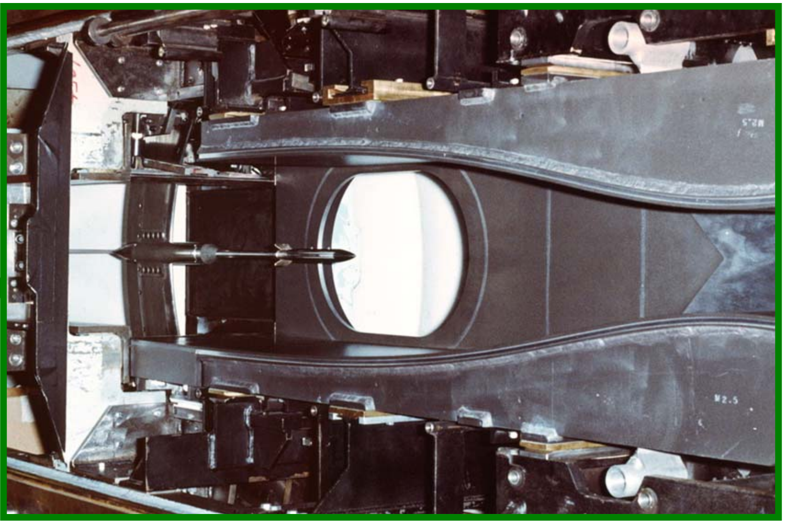
Trisonic Wind Tunnel (TWT)

Supersonic experiments are conducted in contoured nozzles

- Nozzle contour determines Mach
  - Switch out walls to change Mach
- Mach 1.5, 2.0, 2.5, and 3.0



Transonic experiments are conducted in a porous-wall test section

- Any Mach number from 0.5 to 1.3
- Porous walls are needed to:
  - Prevent the reflection of shock waves back onto the model
  - Alleviate choking effects near Mach 1

- The typical wind tunnel test hangs a scale model of a flight vehicle off a sting
- Can pitch through a range of angles of attack during one run

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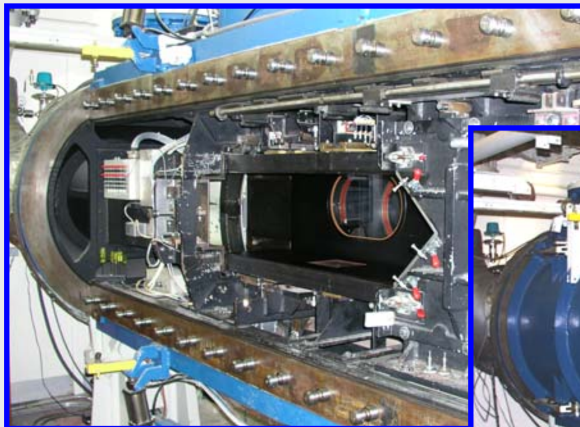
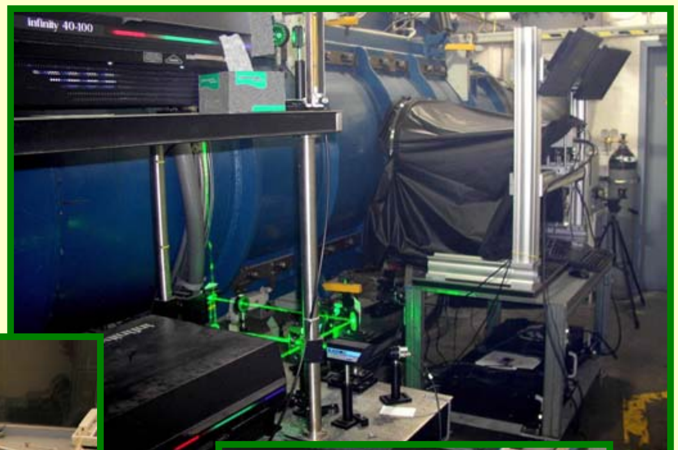
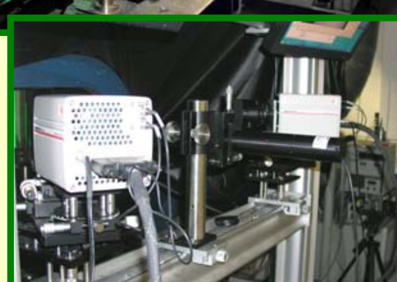
Trisonic Wind Tunnel (TWT)

The test section is enclosed in a pressurized plenum

- Contains the flow through the porous walls
- Makes optical access for measurements more difficult







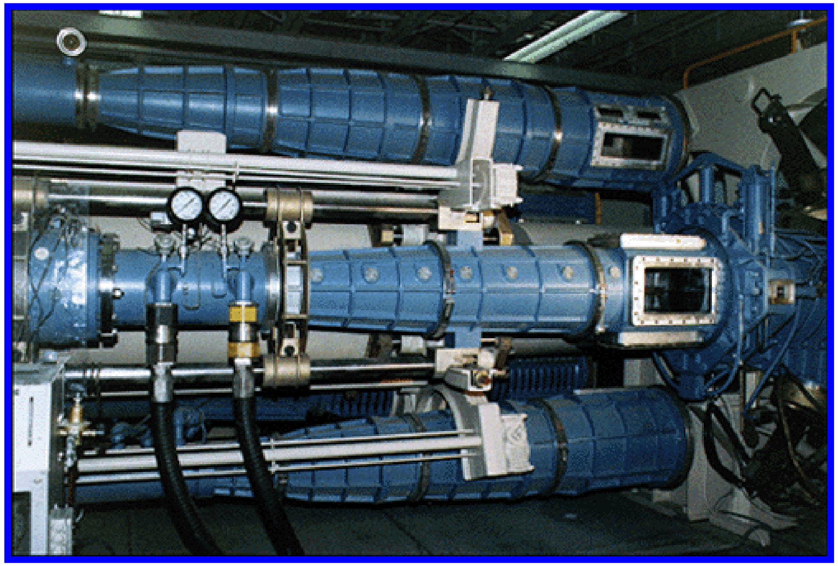
The TWT is surrounded by additional systems needed for various experiments

- Secondary gas supply for simulating rocket motors
- Lasers and optics for advanced diagnostics
- The control console

Hypersonic Wind Tunnel (HWT)

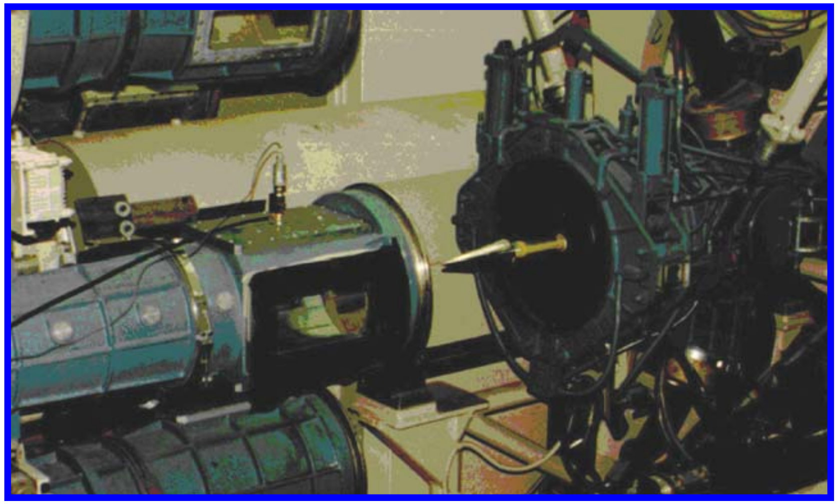
Also a blowdown wind tunnel

- Run times typically 45 seconds with 45 minute turnaround
- Blows down to vacuum
- Mach 5, 8, and 14 using different test sections
- 18" diameter test section
- Testing similar to TWT: pitch a model through a series of angles of attack



Gas source

- Mach 5 runs high-pressure air
- Mach 8 and 14 run nitrogen
  - High Mach numbers have a very low test section temperature
  - CO_2 and other trace gases in air will condense



Hypersonic Wind Tunnel (HWT)

Hypersonics presents many more challenges than lower speeds

High Mach numbers require a much larger pressure ratio to operate

- Nitrogen pressures to 8600 psi
- Blowdown to vacuum

The wind tunnel gas must be heated

- Prevent condensation of nitrogen
- Use electric resistance heaters unique to each Mach number
  - Maximum of 3 megawatt
- Wind tunnel throat is jacketed by a high-pressure water line for cooling

Despite high pressure and temperature, the HWT cannot simulate the real gas effects associated with re-entry

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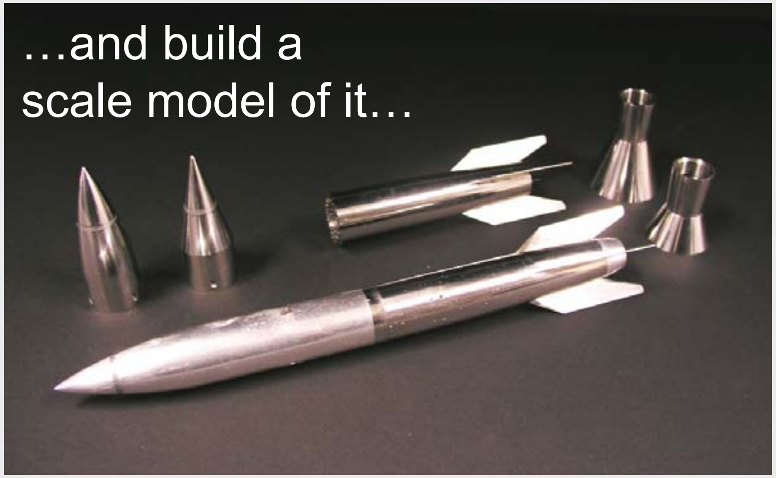
Wind Tunnel Models

Take an actual flight vehicle…

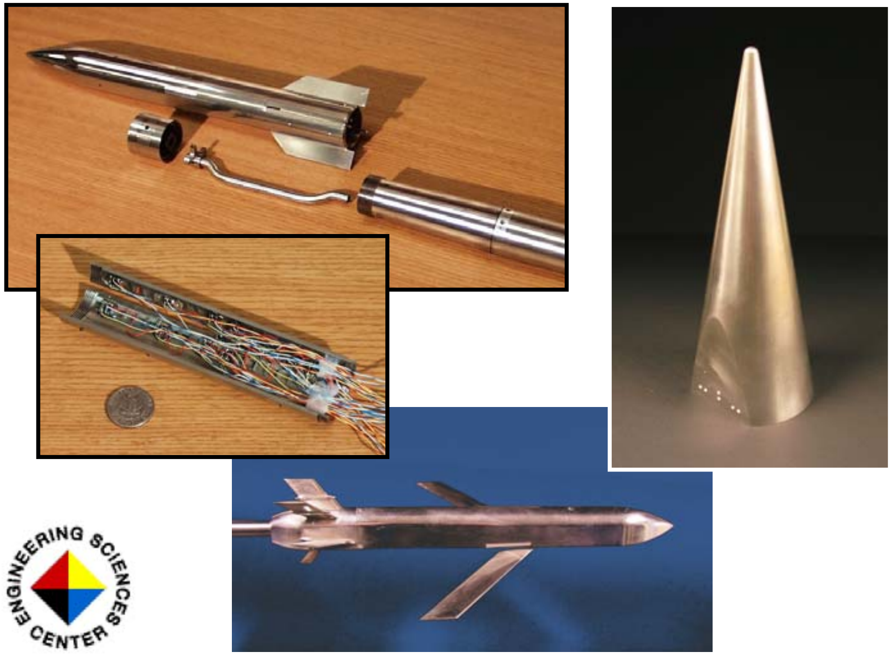
…and build a scale model of it…



…which has features such as:

- Instrumentation
- Geometry changes
- Spin testing

Some other models tested at Sandia:



By necessity, a small model does not exactly replicate the full-scale version

Part of a wind tunnel engineer's job is to understand such scaling issues

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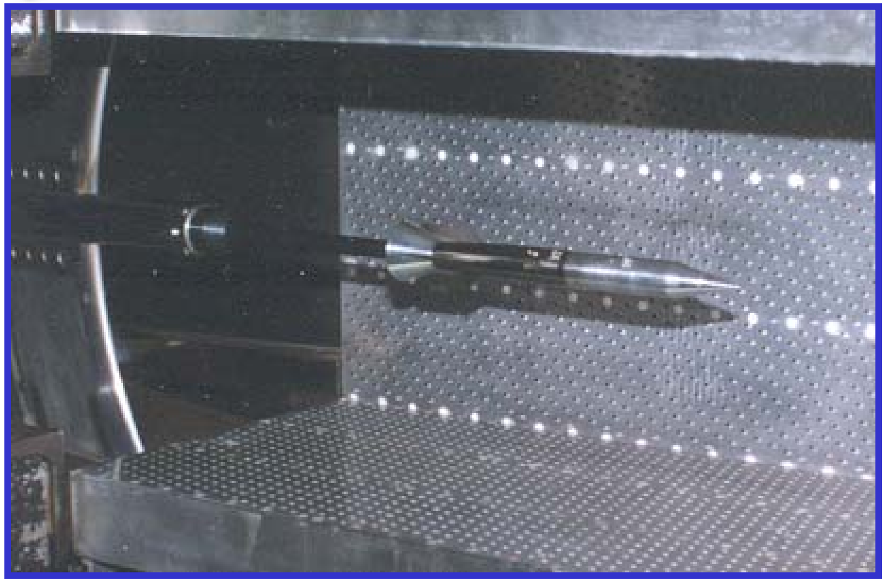
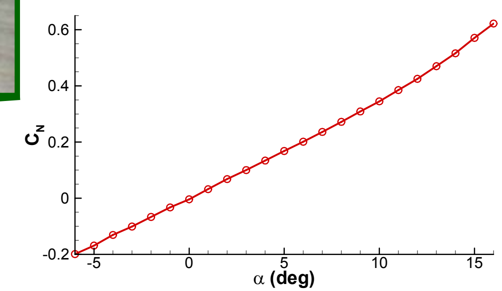
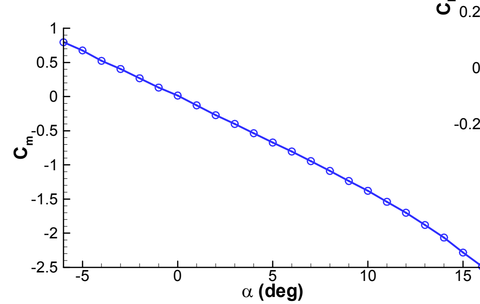
Aerodynamic Measurements



- Determine the aerodynamic forces and moments using an internal strain-gage balance placed inside the model
- Balance elements flex as they are loaded, producing a measurable signal
- Vary parameters such as tunnel Mach number, model angle-of-attack, model geometry, etc

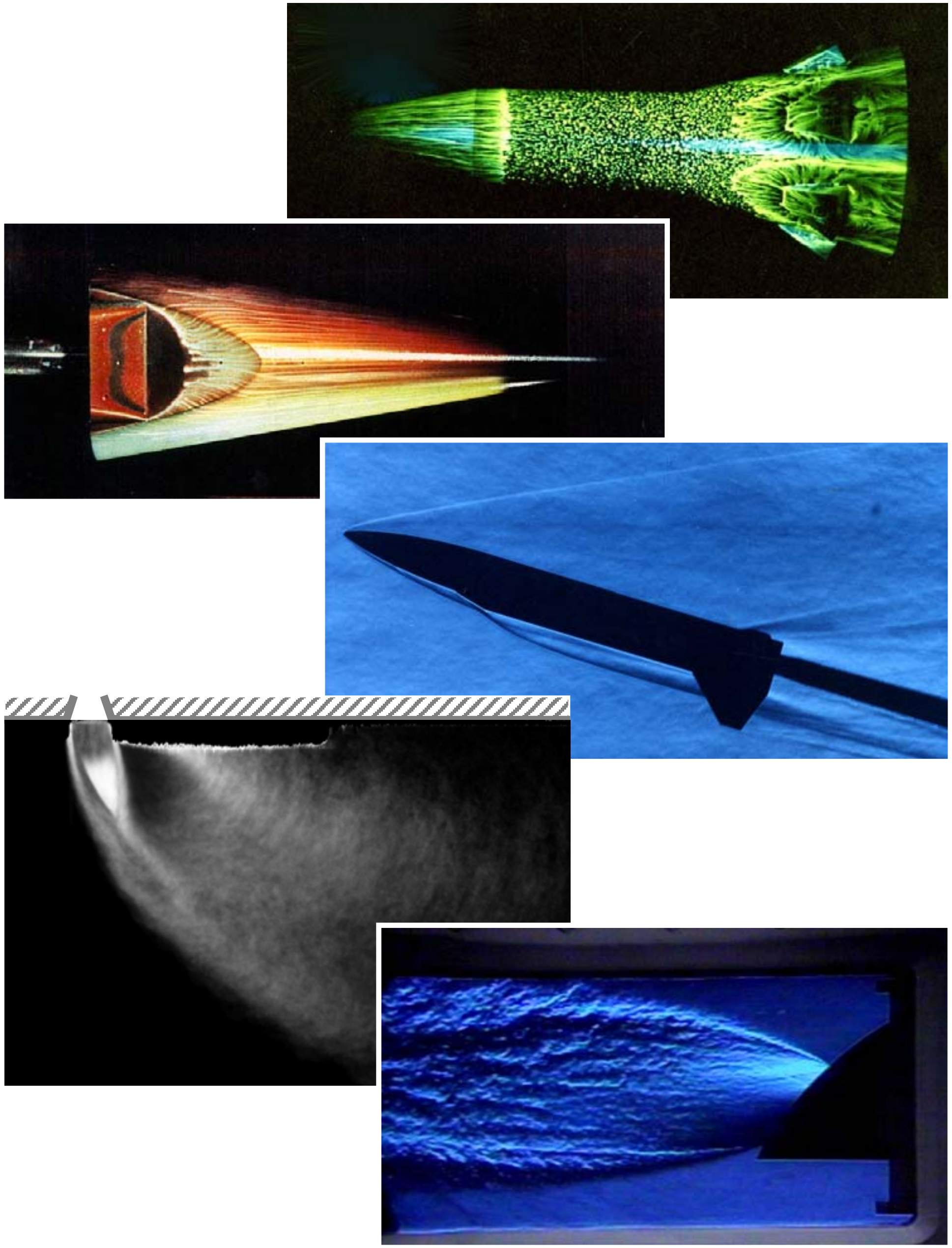




Flow Visualization

- Complement balance measurements with visualization of the gas flow over the model
- Helps to provide an understanding of the underlying fluid dynamics
- Can visualize:
  - Shock waves
  - Surface streamlines
  - Gas mixing

- These images are nice, but we need quantitative flowfield measurements
- Improved technologies allow modern wind tunnel tests to accomplish much more than in the past



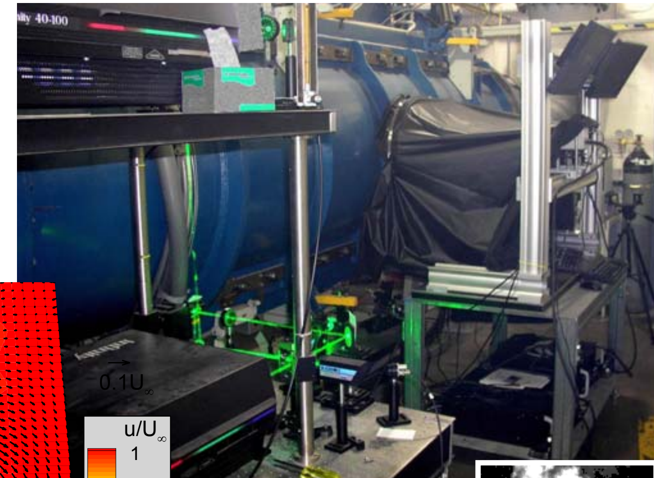
Advanced Measurements

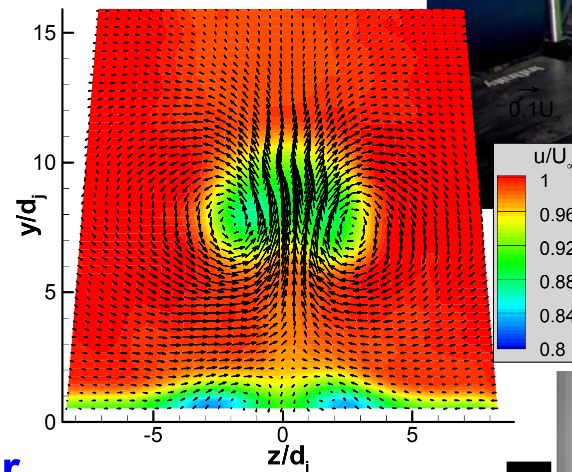
Why do we need laser diagnostics?

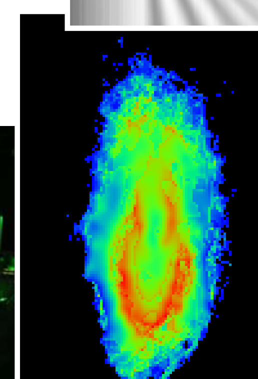
- Some wind tunnel tests need only provide aerodynamic forces…
- …but others must yield a better understanding of the underlying flowfield
- Development and validation of CFD requires high-fidelity measurements
- We can’t let CFD have a monopoly on pretty vugrafs

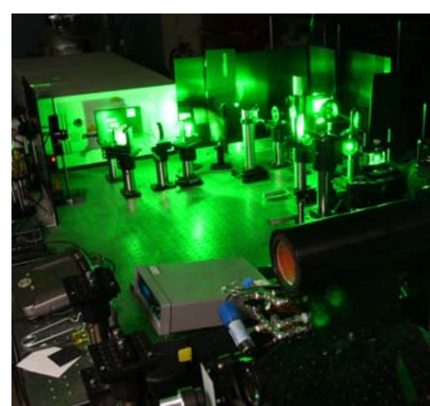
Sandia’s wind tunnels are ideal for advanced measurements and research programs.

- Relatively inexpensive to operate
- Smaller scale is conducive to optical requirements









Advanced Measurements

Particle Image Velocimetry (PIV)

- A plane of 3-D velocity vectors
- Most effective at $M_\infty<3$

Doppler Global Velocimetry (DGV)

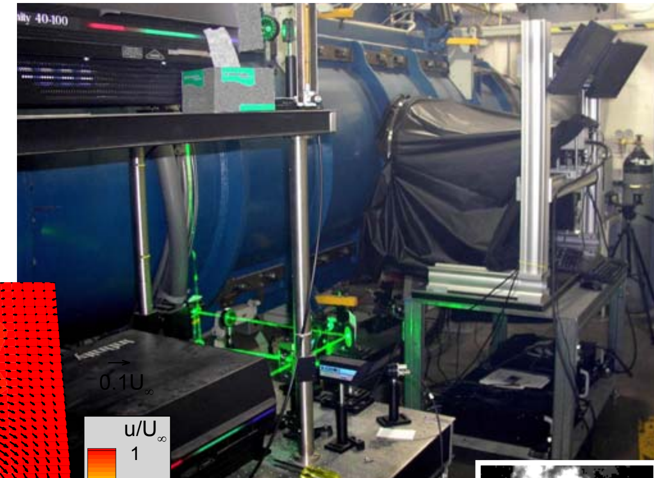
- A plane of velocity measurements
- Well-suited to hypersonics

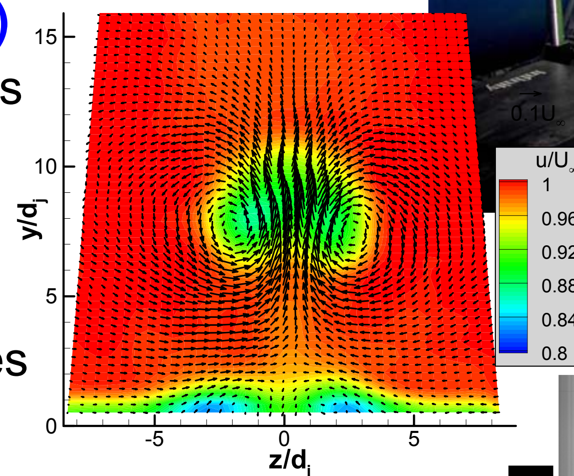
Pressure and Temperature Sensitive Paint (PSP and TSP)

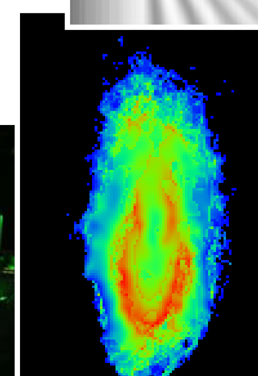
- Measure model surface pressures or temperatures
- Can cover the entire model body, including thin control surfaces

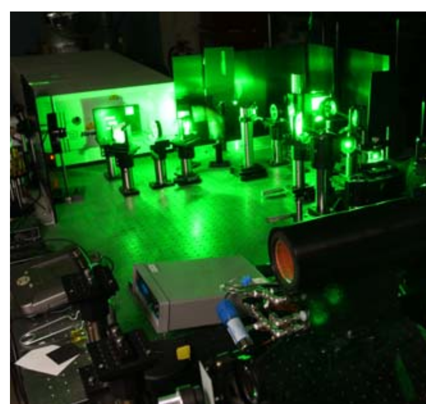
Oil-Film Interferometry (OFI)

- Measures wall shear stress over a model surface
- Transition detection









Jet-in-Crossflow Studies

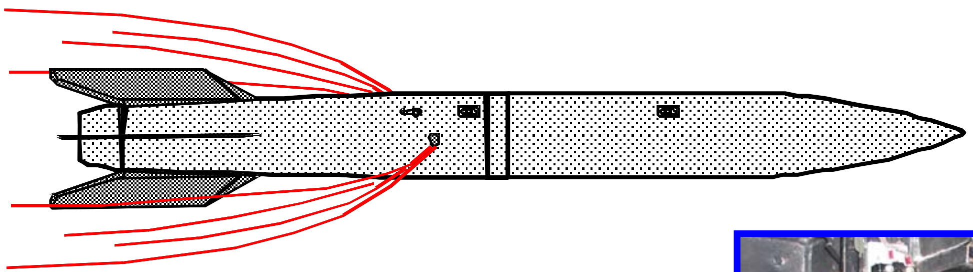
Examine a case study in which advanced diagnostics were used to resolve a flight vehicle concern

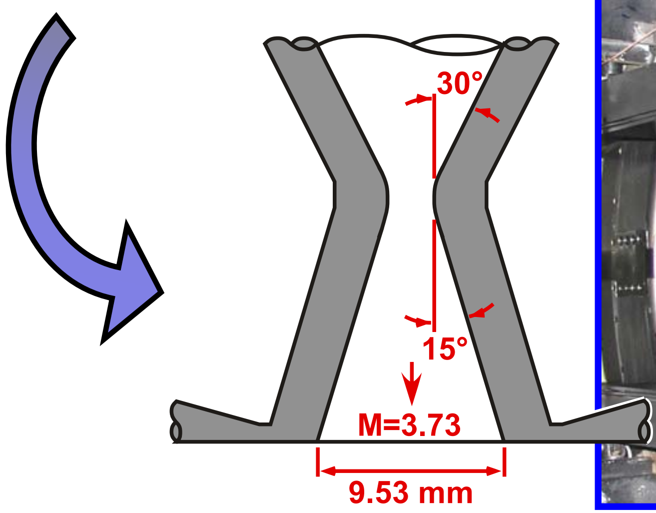
- **In this case, Particle Image Velocimetry (PIV)**

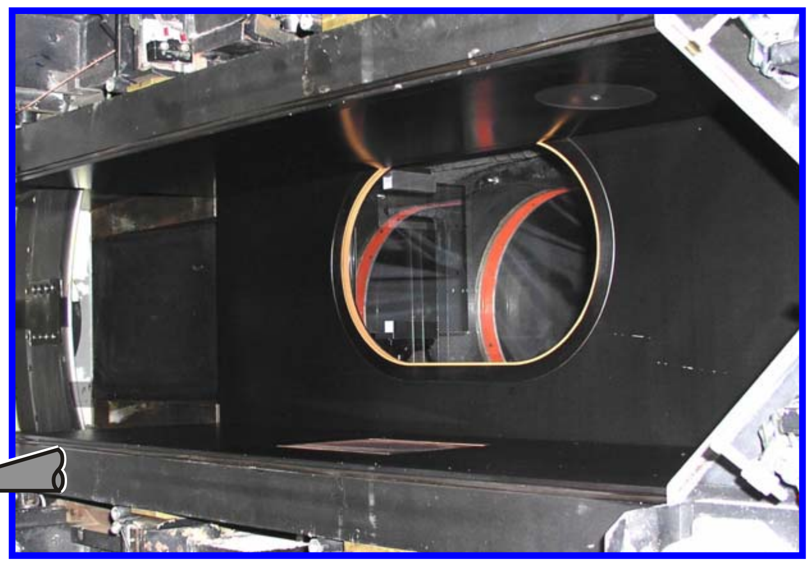
Flight vehicles with both fins and thruster rockets experience an interaction between them.

Our objectives are to:

- Directly detect the vortices responsible for the interaction
- Acquire data for developing and validating computational models







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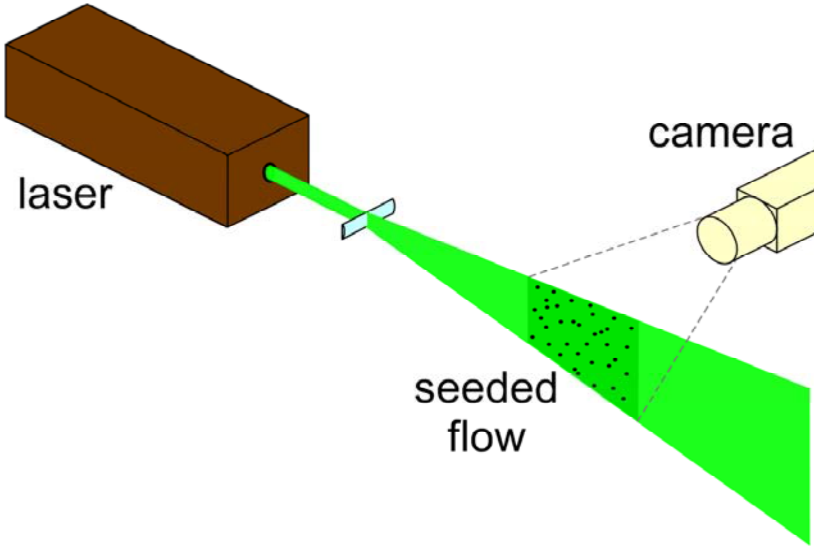
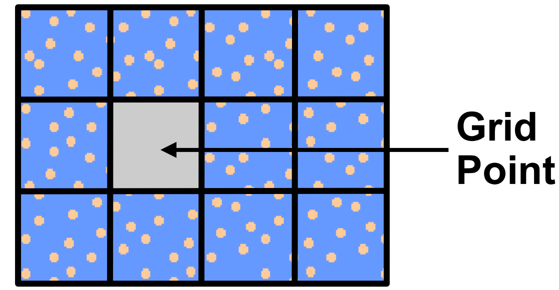
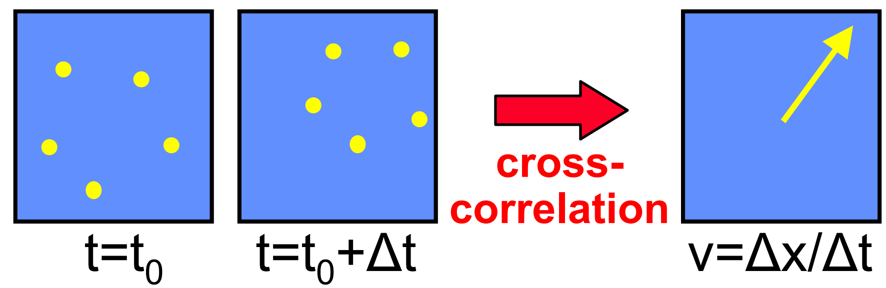
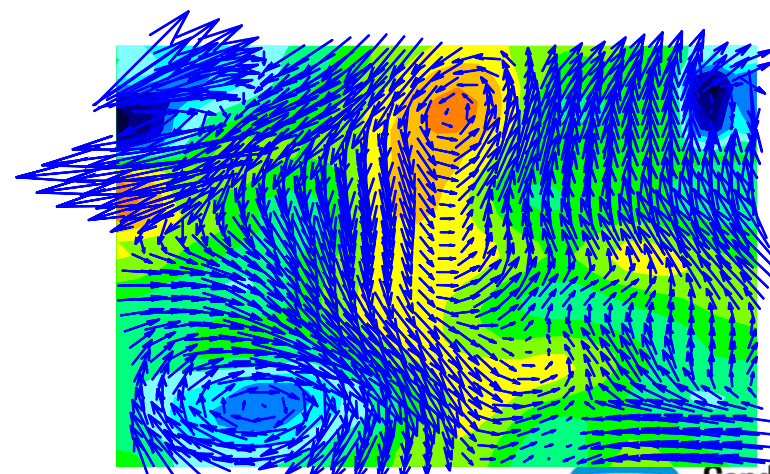
What is Particle Image Velocimetry (PIV)?







- Seed a large quantity of small **particles** into the wind tunnel
- Illuminate with a double-pulsed laser sheet and **image** with a specialized digital camera
- Grid the images into smaller windows
- In each grid window, track a pattern of particles as they move from the first exposure to the second
- Compute a field of **velocity** vectors



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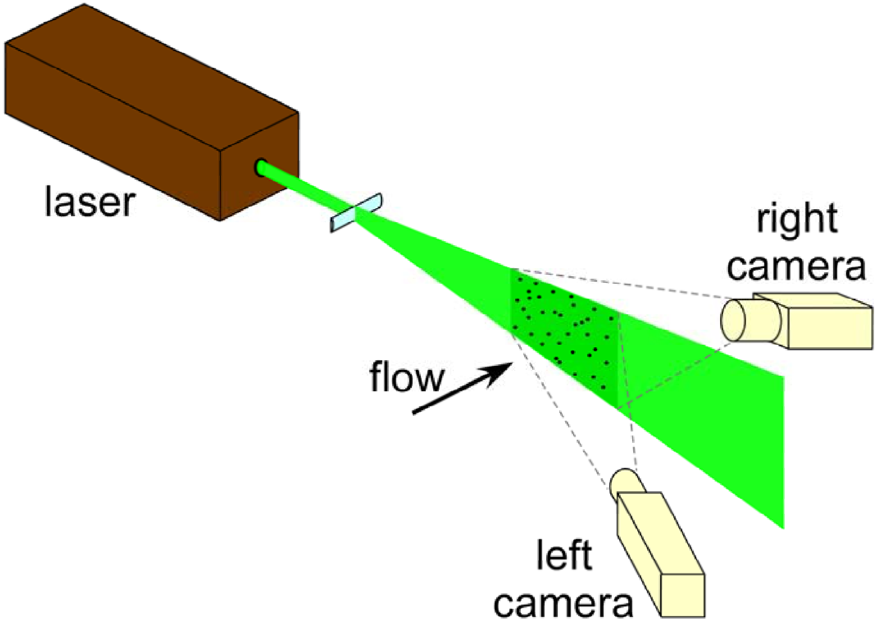
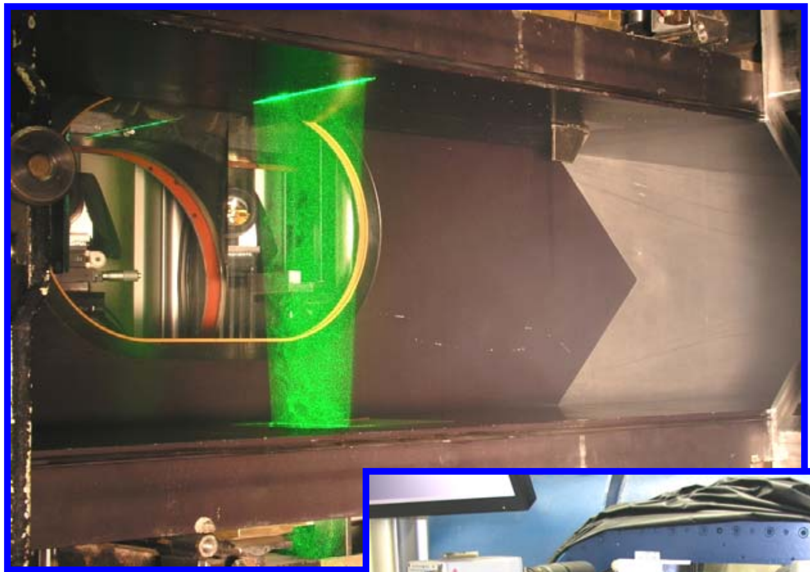
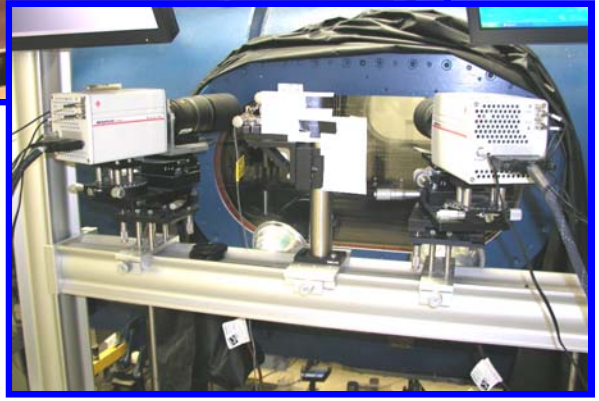
Stereoscopic PIV



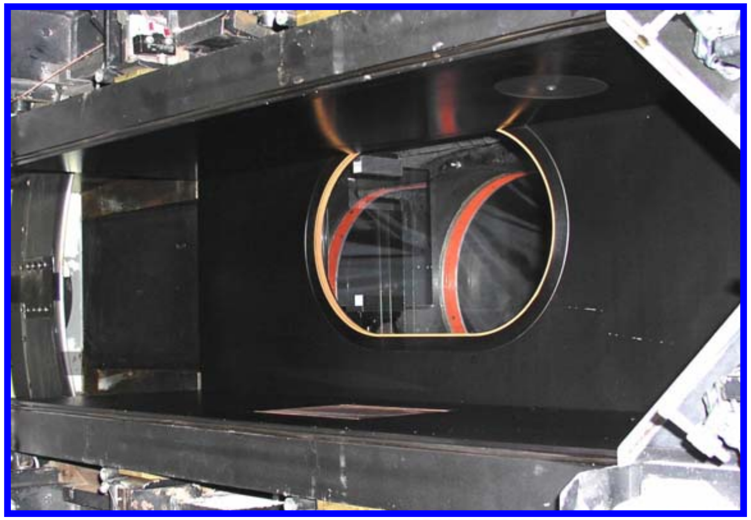




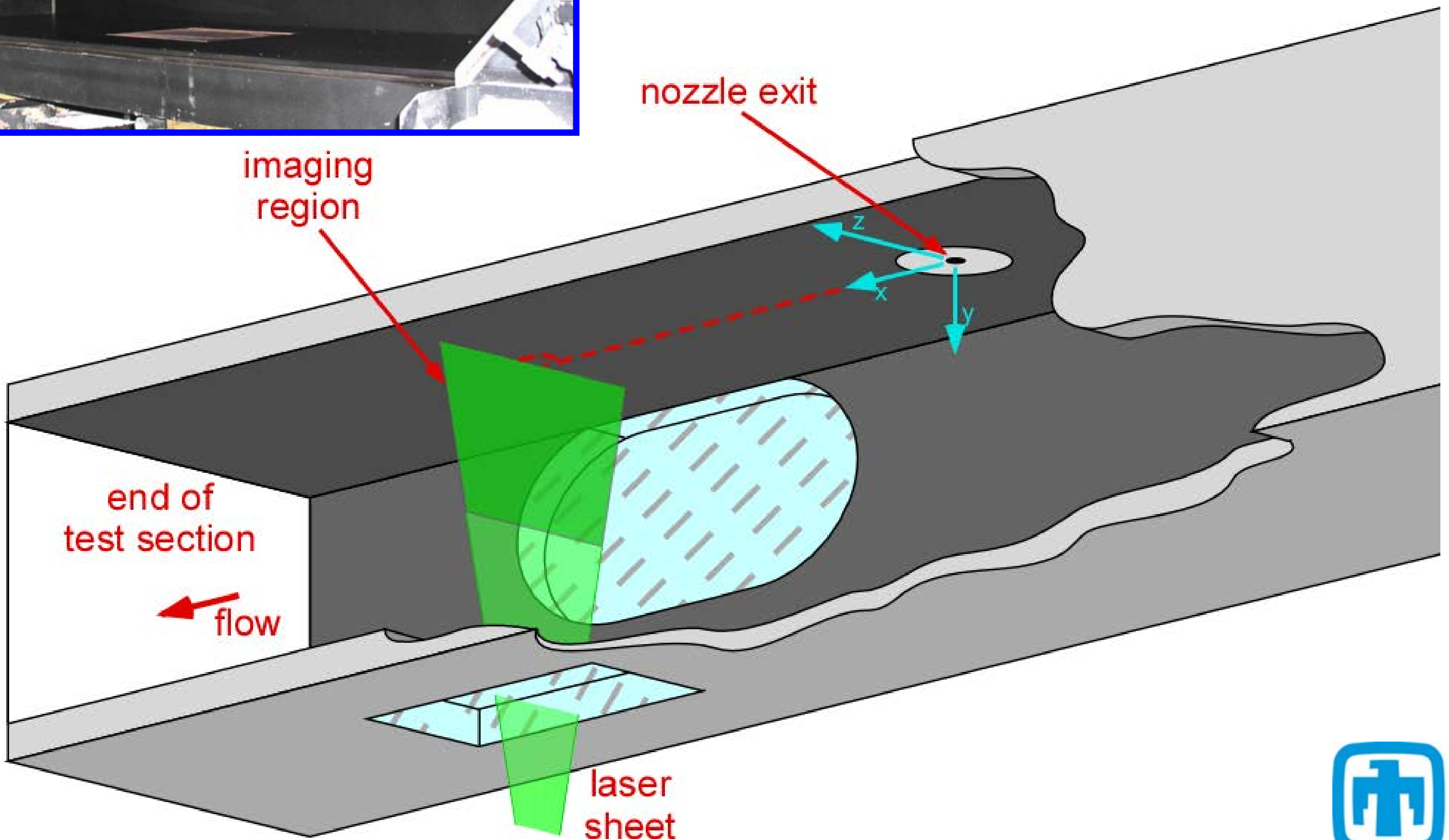
- **Two cameras are used for a stereoscopic view, then the images are digitally reassembled for a three-dimensional perspective**
  - **Much like human vision**
- **It's a lot harder than 2D, but much more flexible**

This is what we need to see the vortices and measure their properties

Laser Sheet Configuration

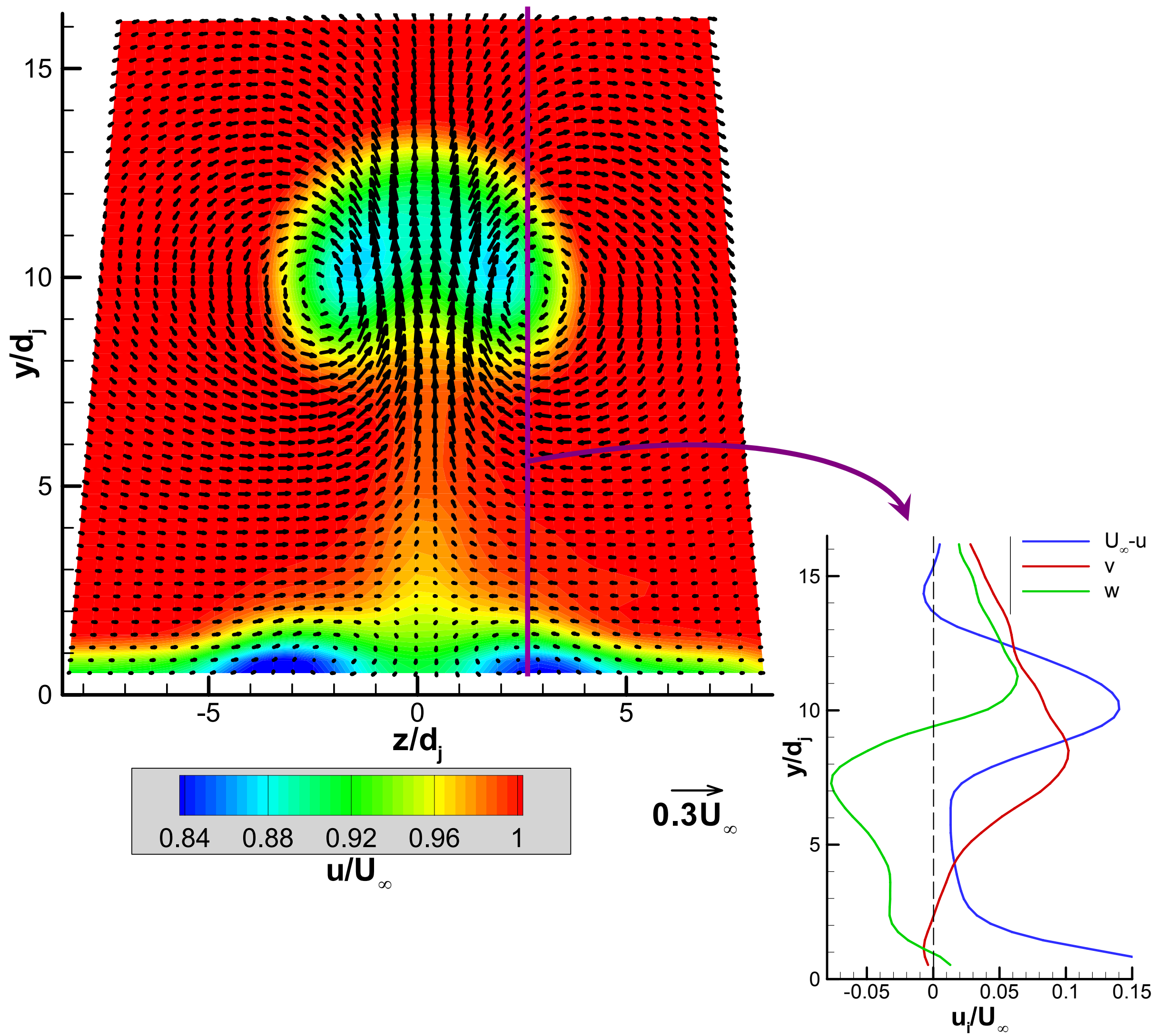


- View the interaction at a single downstream location where a fin would be located.
- Laser sheet aligned to the crossplane of the interaction to directly measure the induced vortices.

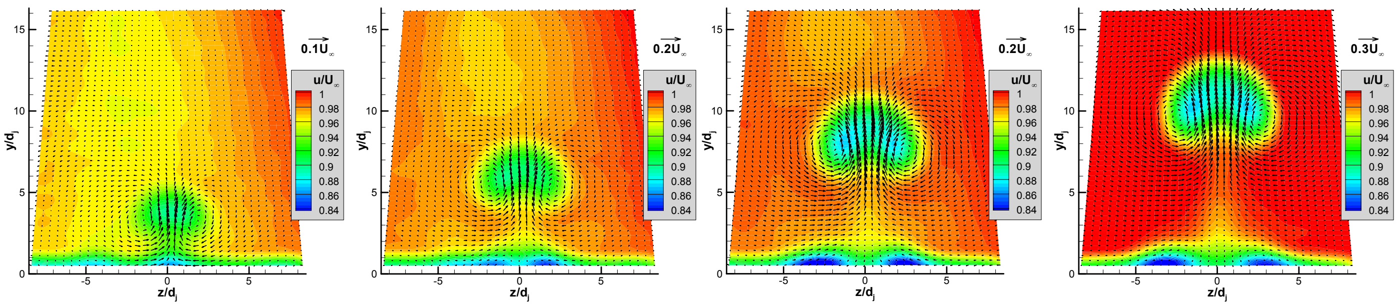


Crossplane Mean Velocity Fields

- In-plane velocities shown by vectors
- Out-of-plane velocities (streamwise component) shown by contour plot
- The counter-rotating vortex pair and the surface horseshoe vortex that are induced by the interaction are clearly visible
    - These vortices are responsible for jet/fin interaction

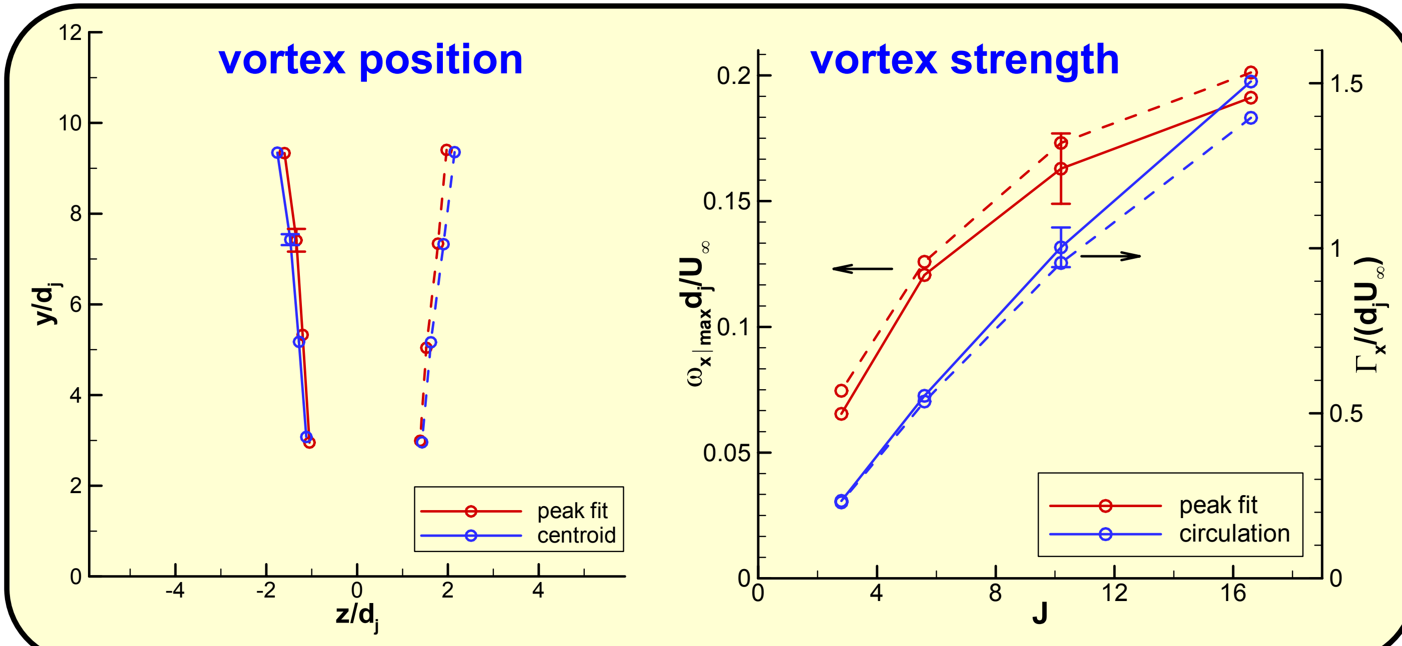


Data Analysis



M_∞=0.8 J=2.8 J=5.6 J=10.2 J=16.7

data reveal vortex characteristics

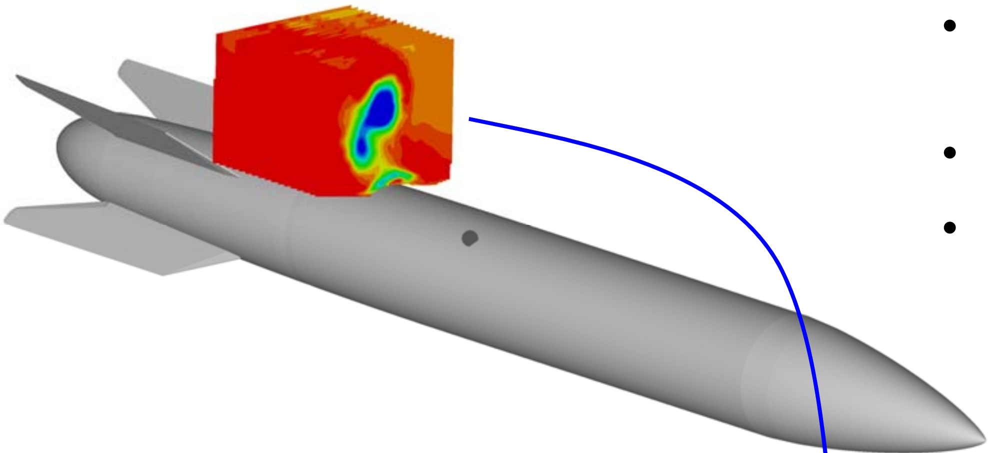


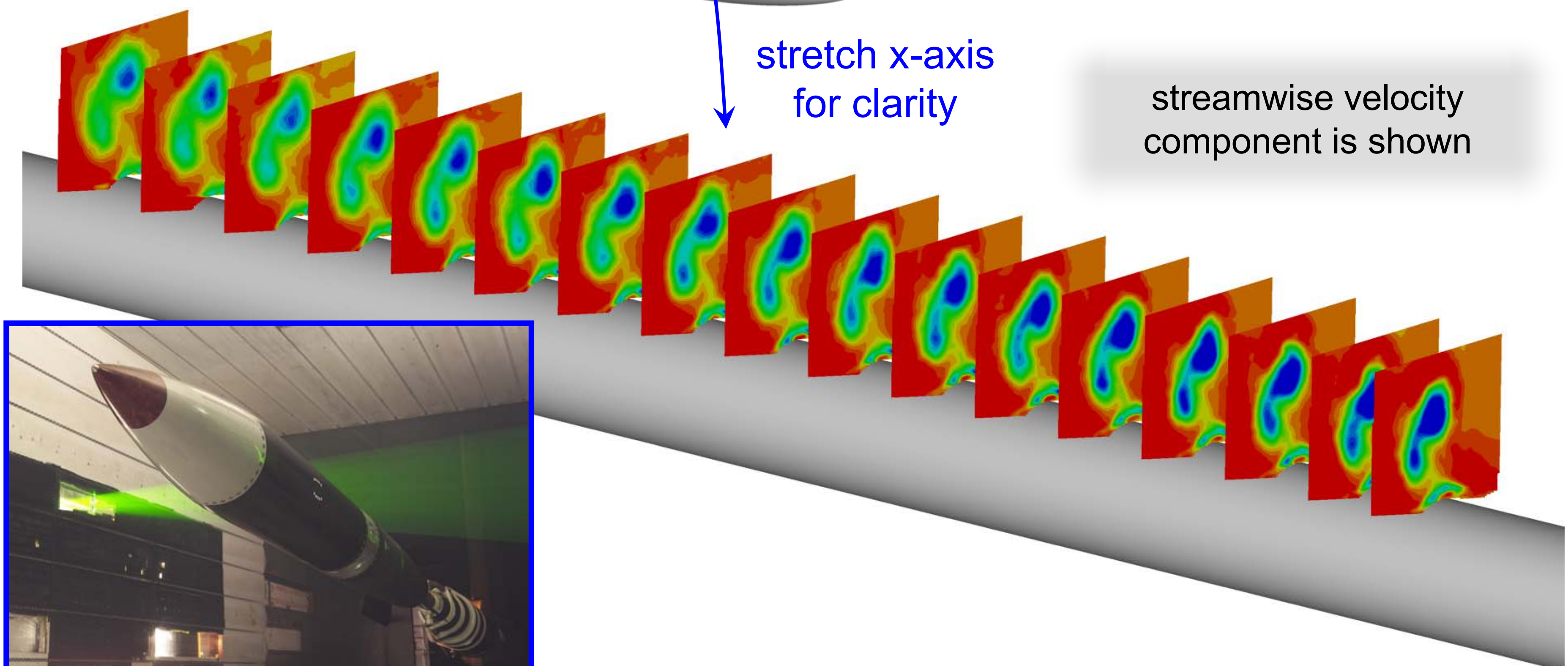
Data such as these are used to:

- **Enhance physical understanding**
- **Provide guidance to vehicle design**
- **Validate computational models**

Full-Scale Wind Tunnel Test

- Test conducted in the NASA Ames 11-Foot Transonic Wind Tunnel
- Transfer PIV to a large-scale facility
- The resulting data set is limited in comparison to the TWT, but important to connecting the study to the flight vehicle

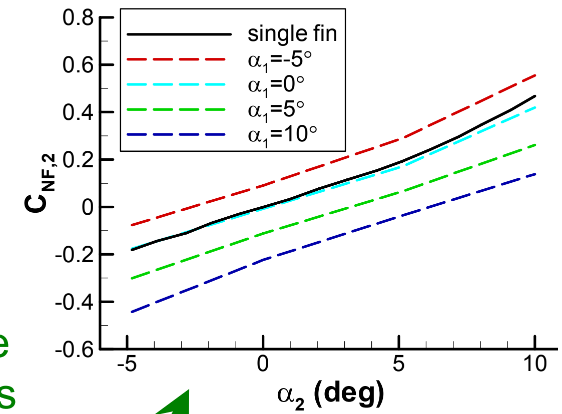




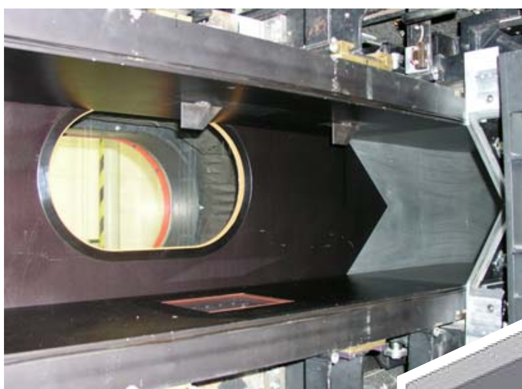
Fin Wake Interactions

We can apply similar technologies to solving other problems….

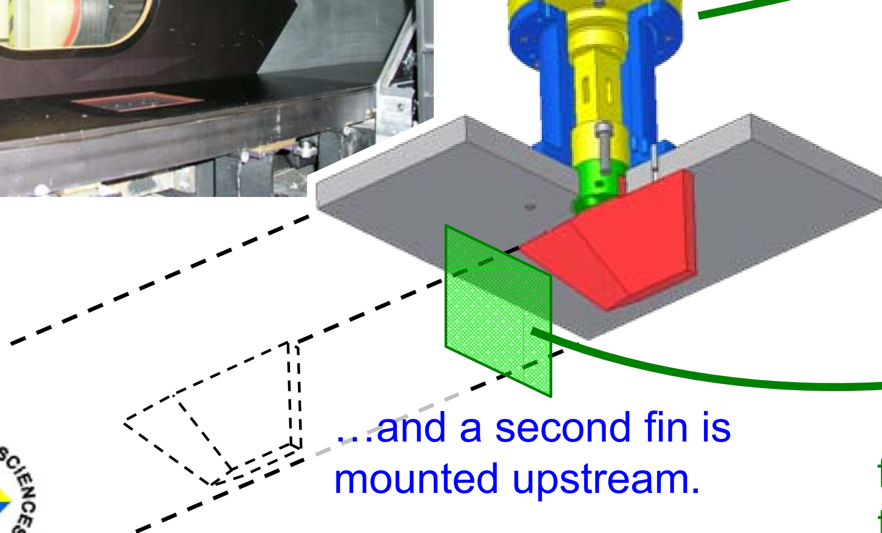
- Vehicles with two sets of fins experience an interaction that dramatically alters aerodynamic control.
- We have neither the knowledge base nor the modeling capability to accurately predict these effects.



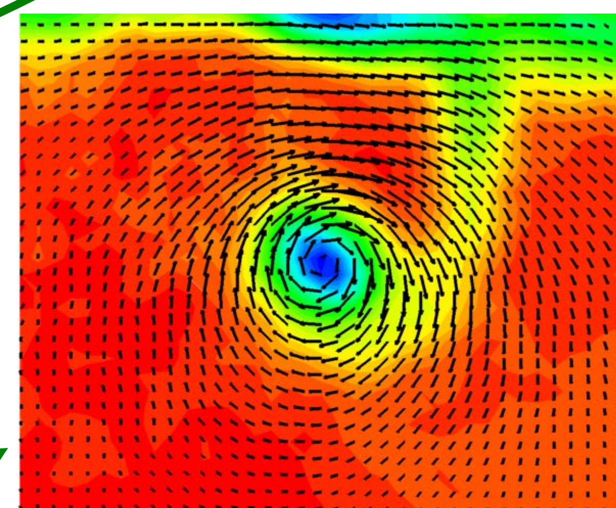
The balance measures the aerodynamics of the interaction...



A fin balance is behind one test section wall…



…and a second fin is mounted upstream.



…and PIV measures the fin tip vortex responsible for the altered aerodynamics.

Hypersonics Research

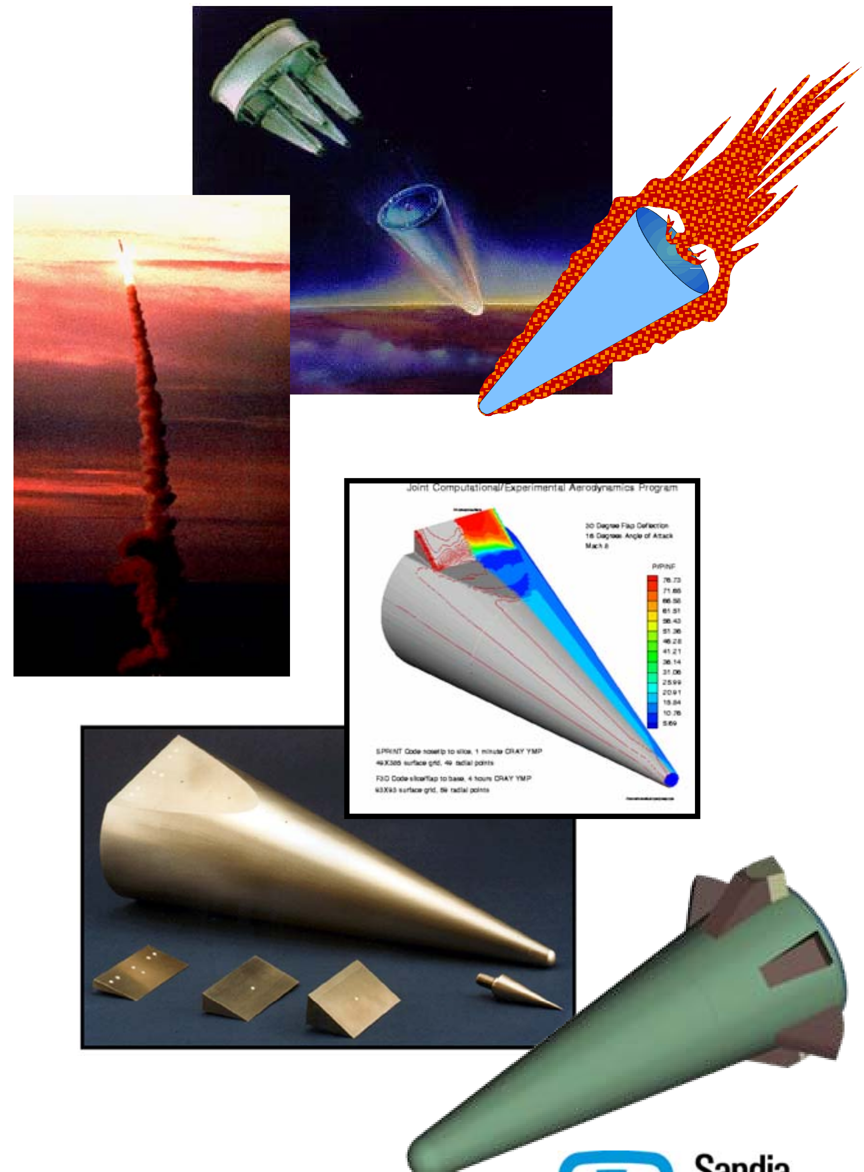
We also apply these technologies to hypersonics programs supporting Sandia re-entry vehicles.

Sandia has numerous hypersonic responsibilities:

- Ballistic re-entry vehicle dynamics
- Component performance due to aerothermodynamic environment
- Thermal protection systems

Current experimental hypersonic studies:

- Aerodynamic force and moment testing
- Unsteady pressure loading on RV's
- Control surfaces and maneuvering RV's
- Assessment of techniques for low-temperature ablation studies in the HWT



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Advanced Measurements for RV Physics

We are developing advanced laser diagnostics for hypersonic testing and code validation.

- At an earlier state of development for the HWT as compared to the TWT.
- Requires techniques applicable to the harsh environment of hypersonic flow.

Laser Rayleigh Scattering

- Flow visualization of shock waves, boundary layers, and wakes

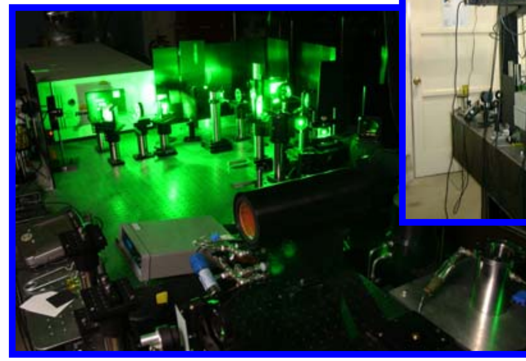
Doppler Global Velocimetry (DGV)

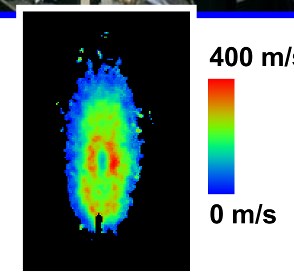
- Particle-based methods (PIV, LDV) are unsuitable for hypersonics

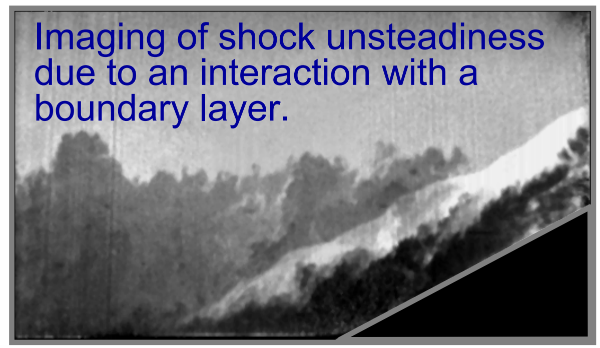
Pressure and Temperature Sensitive Paints (PSP & TSP)

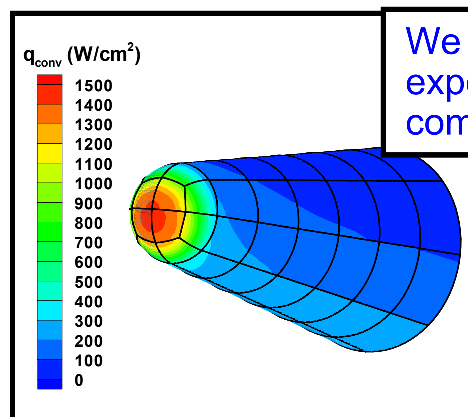
- Measure loading and heating over re-entry bodies, including control surfaces.

Transitioning DGV from a benchtop jet to the HWT.



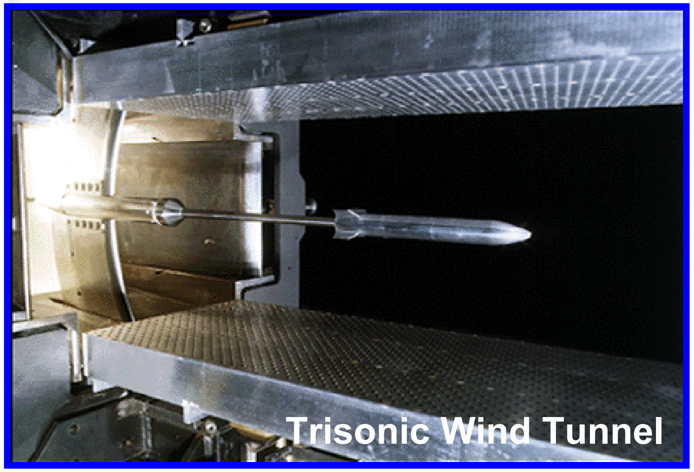






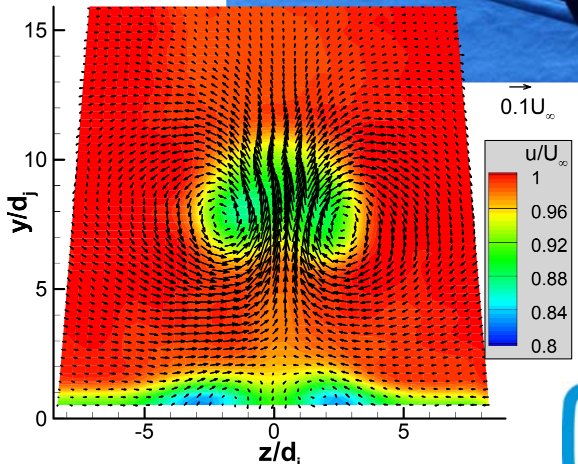
We aim to provide an experimental analogue to computations such as this.

Summary



Sandia's wind tunnels:

- Cover the flight regime pertinent to DOE's defense responsibilities
- Provide aerodynamic characterization of flight vehicles
- Apply advanced diagnostics for measuring the underlying fluid dynamics
- Interact with facilities at NASA, DoD, and internationally to advance technologies



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